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Art. V.—*The Geology and Petrology of the Black Spur Area (Healesville).*

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(With Plates VII. and VIII.)

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[Note:—Numbers in brackets thus—No. (1522)—refer to slides in the University Collection.]

Introduction.

The area dealt with in this paper is an approximately rectangular block of country, stretching from Healesville to Granton in the north-east, and bounded by the Acheron Way on its north-easterly frontage, and by the Don road along its southern extremity; and extending westerly as far as Mt. Monda. Its greatest length is about twelve miles, and its maximum width about ten miles. It is known variously as "The Black Spur,"

the "Blacks' Spur" (after the aborigines) and "Black's Spur" (after the surveyor). I use the former name, since throughout the district it is invariably referred to as "the Black Spur."

THE BLACK SPUR AREA

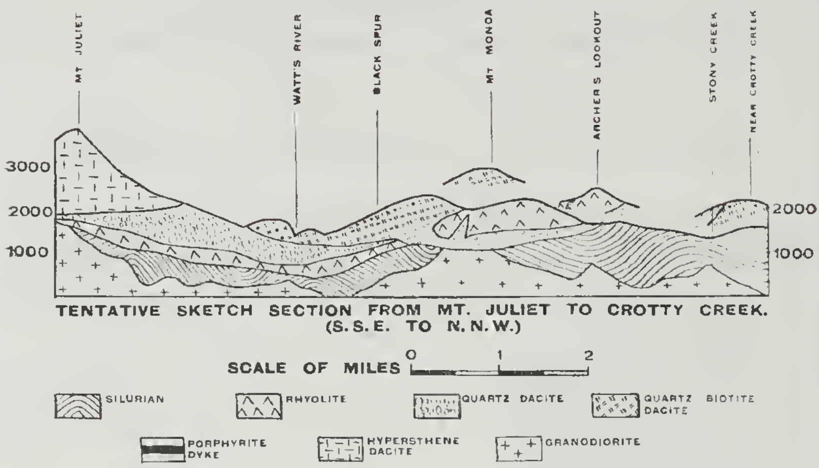

FIG. 1.

A geological map of the area (Plate VII.) and a cross-section (fig. 1) have been prepared. The mapping is generally approximate, and has been done throughout by compass and pacing. Contouring was attempted in order to demonstrate the rugged topography, but time limited such work to aneroid readings during traverses over the northern half of the area, from which form-lines were drawn. Over the southern half extempore form-lines were drawn, based on a few known levels and a knowledge of the country. Where boundaries are plotted with broken lines, considerable linear error may exist, but a full line indicates accurate determination in the field.

I desire to express my sincere thanks to Professor Skeats, Dr. Summers, Dr. Stillwell, Mr. Singleton, and others in the Geology School; to Mr. Ampt of the Chemistry School and to Mr. Mahony of the Mines Department for help with rock analyses; to the Metropolitan Board of Works; to Miss O'Neil and Mr. Vale of Narbethong; to Mr. Chapman, F.L.S., F.G.S., and Mr. Keble, F.G.S., for determining my fossils; and to Mr. McCance and Mr. Bladin.

Previous Work.

A list of the earlier literature concerning the area is furnished in a paper by Dr. N. R. Junner (6) which marks an important advance in the knowledge of the geology of the area. Junner's paper, which has served as an invaluable guide and basis throughout my work, deals with a considerably larger area than is

covered by the present detailed examination. He mapped the outcrops of the granodiorite and the junction of the igneous series with the Silurian sediments; he recognised the variable character of the dacites, but did not appreciate the separate entities of their fourfold division; and he indicated the position of rhyolite, dacite, and tuff on his map by the letters R, D and T respectively, but had not sufficient time to map their boundaries. He made a detailed study of the pyroclastics, and did some work on the Silurian sediments; and gave a description of the physiography.

An unpublished report by Professor Skeats on the Geology of the Maroondah Dam, together with a map showing speculative boundaries of the main rock types, and recognising three of the four dacite flows, was also used.

Physiography.

As described by Junner (6, p. 261) the country falls into three belts from north to south; (1) the valley of the Acheron; (2) the central mountain ranges; (3) the valleys of the Watts and the Yarra. The central ranges of igneous lavas rise up sharply from the open, rolling country of sedimentary character to the north and south, and form a part of the main divide of Victoria. Valleys in this region are narrow, deep, and immature, as opposed to the wide and mature topography of the lower Acheron, the lower Watts, and the Yarra. These rivers rise in the mountain zone. The high ranges radiate as several ridges from Mt. Donna Buang. Spurs radiate from these ridges in turn, and serve as the mediums for roads to cross the hills. The well-known Black Spur is one of these. Low "gaps" mark the junction of the ridges. Streams rising in the dacites have mud bottoms, while those from the rhyolite are stony-bottomed.

Sedimentary Rocks.

Silurian.

The oldest rocks outcropping in the area are sediments of Silurian age, and include mudstones and sandstones, with occasional shales and conglomerates. The sandstones outcrop mainly to the north-east. They are hard and compact, and inclined to induration by iron oxide, resembling very closely the sandstones of the Cathedral Mount. Blue slaty shales showing curious white stains are found interbedded with a friable purple sandstone in a section on the Tarnpirr private road.

Junner (p. 204) records two outcrops of "fossiliferous conglomerate" near Narbethong, one west, the other east of the main road. Unfortunately the western outcrop was not located, but the eastern conglomerate was found in an old road-metal quarry, about 300 yards west of the Old Marysville Road. Six bands of coarse to fine conglomerate, never more than three

feet thick per bed, alternate with very friable shales. A fossiliferous grit bed, varying from six inches to one foot three inches in thickness, directly overlies the uppermost conglomerate bed. The beds dip at 50°W. and strike at 340° (mag.). The individual pebbles are very well rounded, but are never large. They consist of quartzite (the larger sizes), shales and vein-quartz. The grit is similar to fossiliferous grits seen in the Yea-Alexandra district. It is packed with very poorly preserved casts of crinoids and brachiopods, and several identifiable forms were obtained.

Sufficient dips and strikes were obtained to indicate the approximate positions of the anticlines and synclines. The folding is moderately close in character, with high dips. Just east of the Narbethong Post Office the probable existence of a small "crush" zone is indicated.

That the Devonian igneous rocks unconformably overlie the Silurian is indicated by the varying levels at which the junction of the two is found. These vary from 400 ft. at Maroondah Dam to 1000 ft. near Wade's Lookout. Evidently the Silurian was neither level nor peneplaned when the igneous activity occurred.

Near Wade's Lookout the sandstone in contact with the dacite has been altered to quartzite. Section No. (1522) shows it to be a nearly pure quartz rock, consisting of crenulated, interlocked quartz grains, with a very little muscovite. Along the Acheron Way was found a small bedded outcrop of baked mudstone, striking at 280° (?) and dipping at 80°N. It was surrounded by dacitic soil, containing cores of weathered dacite.

Fossil Forms.

Junner records plant remains from the red-coloured sandstones and mudstones in the north of the area. Mr. Chapman has referred them to *Haliserites* (now *Psilophyton*) *Dechenianus* Goeppert—a form characteristic of the Silurian from Wood's Point. Examination of the rocks has yielded poor, but definite remains at several localities. These have been named for me by Messrs. Chapman and Keble.

1. *Fossiliferous Grit, Conglomerate Quarry.*

Casts of: Brachiopoda—*Leptaena* sp. (aberrant form—only known from the Yeringian); *Stropheodonta* (?); *Chonetes* sp. Anthozoa—*Lindstroemia* sp. (Silurian); *Tryplasma* cf. *murrayi.* (Upper Silurian to Lower Devonian); Crinoidea—Numerous casts.

2. *Boulders on the ridge south of the Acheron Way.*

Casts of: Brachiopoda—*Chonetes* sp.; *Stropheodonta* sp.; Anthozoa — *Lindstroemia* sp.; *Tryplasma* cf. *murrayi;*

CRINOIDEA—casts of stems. ARTHROPODA—Cephalic border of a Trilobite, bearing a genal spine.

3. *St. Fillan's.*

PLANTAE—*Psilophyton* (?).

These remains indicate that the beds are of Upper Silurian (Yeringian) Age. The fossil remains in conjunction with the lithological types suggest that the disposition took place under coastal marine conditions.

Igneous Rocks.

The igneous rocks of the area consist of a series of acid lavas. They are described in their apparent order of extrusion.

1. ANDESITE.

No outcrops of andesite have been discovered in the area, but proof of its existence has been afforded by xenoliths found in the quartz-hypersthene-biotite-dacite, along the track to Mt. Monda, and in the quartz-biotite-dacite in the Chosen Valley (S. of Mt. Dom Dom).

Andesite has been recorded from Wade's Lookout by Junner, but sections cut from there and other localities marginal to the flows appear to be chilled borders of the main hypersthene-dacite flow.

The xenoliths of andesite are dark brown in colour, and very fine-grained. A section No. (2343) shows it to be a porphyritic rock, with a felted or hyalopilitic groundmass of fine lathes of felspar set in a glassy base. The hypersthenes form numerous phenocrysts and dominates over the felspar. They show a very slight tendency to form reaction rims of secondary biotite, particularly in the presence of ilmenite; and they have clotted together giving rise to a glomeroporphyritic structure. The felspars are labrodorite with some andesine. They form small phenocrysts which grade into the groundmass, and are very distinct from the felspars of the including dacite. Quartz crystals are absent. The ratio of the groundmass to the phenocrysts is about 2:1.

It is remarkable that no xenoliths of andesite are found in the rhyolite, while they are prevalent in the quartz-hypersthene-biotite-dacite, so close to the rhyolite. This latter when intruding the rhyolite appears to have brought the andesite up with it from below.

2. RHYOLITE.

This has been figured and described by Junner (6, pp. 276-279). His analysis is quoted on p. 65. The rhyolite is "characterised in handspecimens by the abundant quartz phenocrysts, and by the paucity of the femic minerals. Rhomb-shaped sections of glassy or pearly orthoclase can often be recognised." Thin sections show plentiful phenocrysts of strongly embayed

quartz and orthoclase (often microperthite) set in a glassy to microcrystalline groundmass. Femic minerals are almost absent.

This rock outcrops in a long narrow belt, near the margin, or marginal to the igneous rocks, along their northern boundary. It often shows well developed jointing, as in the cliff face at Archer's Lookout and along the Acheron Way.

Tuffs and breccias are developed along the lower spurs north-west of the Hermitage (Narbethong), and boulders of lapilli have been found there. These pyroclastics are well described by Junner (pp. 271-276). Beautifully banded rhyolite, resulting from differential flowage, is found in this locality.

Examination of thin sections Nos. (2347, 2349) shows that in addition to the minerals recorded by Junner, cordierite is frequently present and is characteristic of the rock.

Hills (4) has described a similar rock from the Blue Hills, near Taggerty, and thinks that the two flows are connected.

3. Quartz-dacite.

This dacite outcrops over an extensive area. It abuts the granodiorite in the south, and extends along both sides of the Maroondah Dam, continuing as far north as the Acheron Way. It almost pinches out at Carter's Gap. The rounded hill on the western side of Maroondah Dam represents a volcanic centre of this flow. On its northern slope a large amount of coarse breccia is found, containing angular fragments of sandstone and shale. On the western slope a volcanic agglomerate occurs, with quartzite and sandstone pebbles as big as a clenched fist. A pebble of rhyolite was found here, but no quartz-biotite-dacite fragments could be discovered.

The rock is grey in colour (often greenish from chlorite). It consists of a fine groundmass with numerous glassy phenocrysts of quartz and felspar, together with chloritised biotite, and occasional pink garnets. The rock is closely similar in appearance and composition to the Lower Dacite of the Dandenong series (7).

A typical section No. (1324), (Analysis No. III.), from Maroondah Dam, is a porphyritic rock with a glassy groundmass containing numerous microlites of quartz, and patches of small, aggregated felspars. Flow structure is well developed. The quartz phenocrysts are common and have fantastic shapes, having been deeply embayed by corrosion. The outlines of the crystals are usually sharp. The predominant felspars are labradorite and andesine, in about equal volumes. A few phenocrysts of orthoclase, sometimes showing microperthite, are present. The felspar crystals are also corroded but not so fantastically as the quartz crystals. This is probably due to the cleavage of the felspars tending to maintain a more or less rectangular outline in the crystal. The felspars are often sericitised, and clouded by secondary reactions. They grade in size from the largest pheno-

crysts down to tiny lathes in the groundmass. Bleached biotite often occurs, being generally partially or entirely replaced by chlorite. Chlorite, alone, is frequently observed. A little apatite is included in the biotite. Small ilmenite grains are present. A cordierite trilling, with radial extinction, occurs. It is partially altered to a micaceous substance—pinite (?). In section No. (2338), from Carter's Gap, the felspars show a tendency to clot. The biotite contains zircons; and a cordierite, with marked radial twinning, shows partial pinitisation. An example from the Acheron Way contains a large, altered garnet, which is surrounded and impregnated by an iron-rich chlorite showing beautiful ultra-blue polarisation colours. Small patches of calcite, after biotite or sericitised felspar are common. No. (2340), from Mt. Juliet track (1000 ft. level), is much altered. The felspars are clotted and sericitised, and the ilmenite is altering to leucoxene. An intergrowth of biotite (altering to chlorite) and lathes of felspar is observed.

The chloritisation of this rock is so general, and so characteristic, even in the very freshest of material obtainable from the huge Maroondah Dam quarry, that it cannot be regarded as a weathering effect. The chlorite seems to be of "deuteric" origin, after pyroxene (?), biotite and sometimes garnet.

Near Maroondah Dam the rock contains numerous xenoliths of hornfels. A section No. (2372) shows them to be fragments of altered mudstone.

4. Quartz-hypersthene-biotite-dacite.

This is the first record in Victoria of a dacite which contains quartz and hypersthene phenocrysts freely associated together. It has been found at four separate localities, all marginal to the rhyolite; (1) at Crotty Creek in the north-west; (2) below Archer's Lookout; (3) from the Acheron Way, along an axis of 300° (magnetic) to Mt. Dom Dom, and Bladin's Quarry, near which it disappears under the rhyolite; (4) it reappears along this line of "strike" on the other side of the rhyolite, and continues towards Mt. Monda, merging into the quartz-biotite-dacite in this direction by the replacement of the hypersthene by biotite.

The rock is dark blue when fresh, and is markedly porphyritic. Phenocrysts of clear quartz, white felspar, and frequent but not numerous flakes of biotite are set in a very glassy groundmass. Sporadic pink garnets are characteristic; and pyritic minerals are often seen. Coarse patches develop locally in the normal dacite in the Mt. Monda outcrop. It is closely similar to the Middle Dacite of the Mt. Dandenong series (7), both in appearance and in chemical composition.

A typical section No. (2341), (Analysis No. VII.), from Bladin's Quarry, 2½ miles from Narbethong, on the Spur road, shows that the groundmass is a fine glass, with local develop-

ments of cryptocrystalline texture, exhibiting beautiful flow structure. The quartz phenocrysts are the largest crystals, and are equal to half the volume of the felspars. They show deep embayments and rounding of the edges from corrosion; but such corroded edges are generally sharply defined. The felspars are clear and fresh. Plagioclases predominate as labradorite with some albite and andesine. There is an occasional orthoclase. Carlsbad and albite twins, and zoning are prominent. Hypersthene crystals are the dominant ferromagnesians, but are subordinate to the felspar or quartz in quantity. They show green to pink pleochroism, and contain inclusions of ilmenite and apatite. The rims of the crystals show considerable alteration to a green chloritic mineral, itself secondary after secondary biotite. Sometimes the unaltered biotite remains. Biotite of primary character occurs in thin flexed ribbons, often curving about quartz or felspar crystals. It shows light yellow to brown pleochroism and perfect cleavage. Secondary biotite as coronas, or unorientated aggregates (after hypersthene), is about equally present. Grains of pyrrhotite appear occasionally. There is no garnet in this section.

Section No. (2344), also from Bladin's Quarry, is from the contact with the rhyolite. It is quite normal. The phenocrysts are smaller and apatite is more abundant. A cordierite trilling is seen, and a large pink garnet, altering to an iron-rich chlorite with fine ultra-blue polarisation colours. The garnet is included (?) by orthoclase crystals, which are much sericitised, and contain zircons. A large orthoclase contains a centrally included fragment of primary biotite. The groundmass is entirely glassy, and most beautifully marked by flow structure. A specimen from the Crotty Creek turn-off, No. (2342), differs in that the groundmass is crypto-crystalline. The felspars show coarse lamellar twinning, and contain inclusions of more basic felspar, as shown by the higher refractive indices of the inclusions. One was sufficiently twinned for an extinction angle to be measured. This was 30°, indicating anorthite. The hypersthene crystals are more numerous and contain inclusions of ilmenite and plagioclase. They all show stages of the hypersthene-biotite reaction, from hypersthene with biotite coronas to clots of secondary biotite, representing complete reaction. Primary biotite contains inclusions of zircons, with pleochroic haloes, ilmenite and fragments of felspar. Apatite is common, and there is a trilling of cordierite. No. (2343) from the Mt. Monda track near the rhyolite junction, resembles the Crotty Creek specimen. A hypersthene is present abutting an orthoclase crystal. A layer of secondary biotite marks their junction (see fig. 2). This demonstrates beyond doubt the character of the reaction.

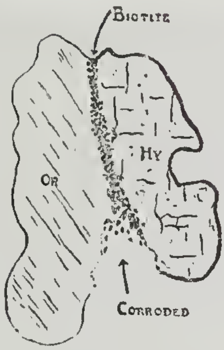

Fig. 2.

No. (2345), nearer to Mt. Monda, illustrates the linear gradation of quartz-hypersthene-biotite-dacite into quartz-biotite-dacite. There is a marked decrease in the amount of hypersthene, and a corresponding increase in the amount of biotite. Much of the hypersthene shows alteration to secondary biotite. A pink garnet is present, framed with secondary biotite.

Mode of Occurrence.

The quartz-hypersthene-biotite-dacite is intrusive into the rhyolite. At Bladin's Quarry it is seen in sharp contact with the latter rock, the contact bearing at 290° (magnetic). The dacite dips under the rhyolite at the junction at an angle of 60° in a southerly direction. It is extremely well jointed into blocks or columns, and these dip away at 40° to the north, at right angles to the contact, suggesting growth columnar fashion from the contact inwards.

The rhyolite at the junction shows a slight mineral alteration, which increases as the contact is approached. This metamorphic zone, while never more than 10 ft. wide, can be traced all along the contact from the Acheron Way to Bladin's Quarry. Thus, in section No. (2386), ten feet from the contact, the felspar in the rhyolite is partially sericitised; the groundmass is locally coarse; and small patches of fine grained quartz and femic aggregates have developed. No. (2388), two feet from the contact, has the orthoclase generally sericitised, and a coarser groundmass. Strings of blue tourmaline are present and the fine aggregates have developed into coarse clots of a green femic mineral (chloritised biotite (?)). Grains of magnetite are associated with these clots. At the contact macroscopic crystals of green biotite (?) are developed. In No. (2387) these appear as flexed green crystals which are strongly pleochroic and have a high double refraction. They show perfect cleavage and seem chloritised. Magnetite grains are included. Blue tourmaline is prevalent as crystals and as fine stringy or mossy aggregates. The groundmass has been recrystallised. Near the summit of Mt. Dom Dom, No. (2384), blue tourmaline is strongly developed, and shearing and foliation are evident.

The dacite tapers out under the rhyolite just west of Bladin's Quarry, and reappears again on the Mt. Monda track on a continuation of the "strike" of the outcrop extending from the Acheron Way to Bladin's Quarry. It V's up the valleys as would be expected from its dipping junction. On the Mt. Monda track the rhyolite shows a development of biotite where the dacite appears from under it. Apparently the rhyolite forms only a thin cover, and has been considerably metamorphosed. No. (2350), from near the contact contains more albite than usual. Three large cordierites are observed altering to pinite; and tourmaline occurs as crystals of trigonal outline. An intergrowth of quartz and decomposed felspar is seen. Biotite is prevalent. The groundmass retains its glassy character. In No. (2351) at the contact brown and blue tourmaline are a feature, as crystals and as mossy aggregates, often bordering crystals. Biotite and secondary mica have developed, and the felspars are sericitised. The groundmass is micro- to cryptocrystalline from recrystallisation.

Small xenoliths of typical rhyolite have been found in the dacite outcrop below Archer's Lookout.

Owing to the minor character of the intrusion, and to the lithological nature of the sediments, little evidence of the relation to Silurian rocks is apparent, but at Crotty Creek, at the eastern edge of the dacite, there is a sedimentary rock of schistose habit. A section No. (2363) contains a large amount of muscovite, arranged more or less in foliation planes. There is no trace of plagioclase or of large quartz crystals, although certain areas have a related extinction. No biotite is present, and crenulated quartz grains make up the remainder of the rock. These show strained polarisation phenomena.

The dacite appears to have intruded as dykes or sills into fissures in the rhyolite, or into the planes of weakness between the rhyolite and the sediments. It may represent a chilled border phase of an upward stoping magma, which broke through to the surface in places, or may have been exposed only by erosion. Fissuring of the rhyolite from differential floating would permit the intrusion of the linear outcrop described.

5. Porphyrite Dykes.

(1). Junner describes a patch of granodiorite, extending from the Malory's Cascades, east of Archer's Lookout, down to the Silurian sediments. Four traverses, through dense undergrowth, failed to locate the granodiorite; but in its place were discovered a patch of quartz-hypersthene-biotite-dacite of nearly the same dimensions, and a porphyrite dyke, four chains wide, extending from the dacite across the saddle south-east of Archer's Lookout, and causing the Malory's Cascades.

This dyke could not be traced in the dacite, but seemed to be an apophysis of it. Fresh samples from the Cascades were

similar to the granodiorite in hand specimen, consisting of quartz, white felspar, and biotite; and garnets. Its porphyritic character is masked.

A section No. (2353) from Malory's Cascades displays a markedly porphyritic rock, with a microcrystalline groundmass of quartz and orthoclase as a setting for deeply embayed phenocrysts of quartz, plagioclase, and biotite. The plagioclase is labradorite, with some andesine, and is often sericitised. The quartz crystals are large and most irregularly shaped. The biotite occurs in large primary crystals and includes quartz, felspars and zircons —the latter with dark pleochroic haloes. Apatite, ilmenite, and pyrrhotite are common accessories. A secondary radiating micaceous mineral commonly replaces biotite, while retaining the inclusions. Clots of biotite, muscovite, and quartz form coarse patches in the groundmass. A large shattered pink garnet rimmed with chlorite and containing inclusions of quartz and biotite is present.

The contact effect of the dyke on the rhyolite is well displayed in specimens from the saddle south-east of Archer's Lookout. The dyke No. (2354) shows small blue tourmaline crystals near the margins of the phenocrysts. No. (2352) from the rhyolite has green and blue tourmaline strongly developed as mossy aggregates and as crystals bordering the phenocrysts, and filling the cleavages and cracks. Crystals of andalusite, with strong pink to colourless pleochroism, are found, in one instance associated with a fibrous substance, (sillimanite (?)). Yellowish, pinitised crystals of cordierite are common. The groundmass has been recrystallised and is commonly coarsely microcrystalline.

(2). A porphyrite dyke intrudes the sediments near Toolangi, along the New Chum road. It resembles a hornblende-granite in hand specimen, and consists of crystals of quartz, pink and white felspars, and green biotite, resembling hornblende, set in a fine groundmass. A section No. (2364) shows that it is a coarsely porphyritic rock. The groundmass is microcrystalline, and small in quantity. The felspar phenocrysts vary from microcline with sharp cross hatching, to strongly zoned labrodorite, and andesine. Quartz is present as corroded phenocrysts, or in granophyric intergrowths, microcrystalline or coarser, with orthoclase. There are large flakes of brown biotite containing pleochroic haloes; and small mossy aggregates of tourmaline occur associated with sericitised felspars.

This second dyke is probably associated with the granodiorite, whereas the first is part of the quartz-biotite-dacite series.

6. Quartz-biotite-dacite.

This lies in a belt between the rhyolite and the quartz-dacite, and forms the Black Spur. It is well exposed in the roadside quarries from Fernshawe to the top of the Spur (3 miles from

Narbethong). At Carter's Gap it ends in almost precipitous slope of about 300 ft. descent, and abuts a narrow neck of quartz-dacite at the foot of the slope, appearing to overlie it. It is similar in character to the Middle Dacite of the Dandenong series (7).

It is a dark slaty-coloured rock, bluish on a fresh surface. Phenocrysts of quartz and white felspar, occasionally of quite large dimensions, are characteristic. Biotite and garnet are more prevalent than in the quartz-hypersthene-biotite-dacite. Pyrrhotite appears occasionally.

A typical section No. (2356), (Analysis No. V.), is from a quarry about 4½ miles from Narbethong, on the Black Spur road. The groundmass is glassy to cryptocrystalline, and appears to consist of quartz and orthoclase. Flow structure is not very evident. The larger phenocrysts are of quartz and plagioclase, all showing the effects of corrosion. The plagioclase consists of labradorite, and to a lesser extent andesine. In places the felspars show shearing, and strained polarisation. Zoning is eminent, and there is a tendency towards clotting. A coarse patch of ophitic character shows numerous small plagioclase and biotite crystals caught up in a large quartz phenocryst. Large ribbons of primary biotite are present, often flexed, and containing pleochroic haloes centred about zircons. Two small phenocrysts of hypersthene occur, edged with secondary biotite; and ghosts of hypersthene (?), replaced by chlorite, calcite and micaceous or serpentinous minerals, are seen. Two pink garnets are present, unshattered. They are rounded by corrosion, and bordered with chlorite (after biotite(?)), but preserve something of a rhomdodecahedral outline. One contains small inclusions of biotite, while the other is associated with pyrrhotite.

A specimen No. (2377), from a quarry just south of the 5-mile post on the Black Spur, carries a xenolith of rhyolite, and has been semi-propylitised. The dacite contains cubes of pyrite, and the felspar is extremely sericitised. The groundmass coarsens locally about the pyrite, having been recrystallised during the introduction of the sulphides. The xenolith is divided from the dacite by a microcrystalline layer, containing minute trigonal tourmalines(?). In No. (2376), from Fernshawe, coarse bands are found, apparently the last part of the base to consolidate, since crystals of quartz grow columnar fashion towards the centre from both glassy walls.

Near the Devil's Elbow, and along the main divide, patches of coarser rock are found, rich in garnets. Two sections Nos. (2378-2379), from the Devil's Elbow, show very large phenocrysts of quartz, felspar, and biotite, set in a microcrystalline groundmass of quartz and orthoclase. The felspars are basic labradorite and a little andesine. The phenocrysts are strongly corroded, and in places only fragments in optical continuity remain. The biotites are generally fresh. Corroded hypersthenes are occasionally present, with deep coronas of green biotite. The garnets are comparatively large, shattered, and associated with chloritised biotite.

These coarse patches may be local developments in the dacite, or may be recrystallised fragments of the quartz-hypersthene-biotite-dacite, regarding the latter as a chilled border phase of the original magma chamber.

Relation to the Quartz-hypersthene-biotite-dacite.

These two dacites are closely similar. A micrometric analysis shows:—

		Q.H.B.Dacite.		Q.B.Dacite.
Quartz	-	13·18	-	11·46
Hypersthene	-	6·24	-	1·63
Biotite	-	4·28	-	13·95
Felspars	-	28·92	-	27·04
Groundmass	-	48·00	-	45·65

The only marked difference is in the relative proportion of biotite to hypersthene; and as Mt. Monda is approached from the north-east, the amount of hypersthene in the quartz-hypersthene-biotite-dacite decreases and the biotite increases, until the rock becomes a quartz-biotite-dacite without any sharp junction being observed. The evidence suggests that the quartz-hypersthene-biotite-dacite is a chilled intrusive facies of the quartz-biotite-dacite.

7. Hypersthene-dacite.

This rock outcrops widely over the south-eastern part of the area. It is similar, both chemically and mineralogically, to the hypersthene-dacites of Macedon and the Dandenong Range series, and evidences several interesting reactions.

It is a light-coloured rock of an apparently fine, even texture, which masks its porphyritic character. The colour darkens locally where the groundmass is more glassy. It differs from the other types in the area by the entire absence of quartz phenocrysts, and the increased visibility of the biotite. The absence of garnets is characteristic.

Examination of a thin section from Mt. Juliet summit, No. (2330), (Analysis No. VIII.), shows that the rock consists of phenocrysts of labradorite and hypersthene, with smaller and less numerous crystals of ilmenite and biotite, set in a fine granulitic groundmass of quartz and orthoclase, with some biotite and ilmenite. Occasional coarse patches appear in the groundmass. The felspars form small but numerous phenocrysts. They are corroded, strongly zoned, and twinned (albite and Carlsbad laws), and show a general extinction angle of 25°, i.e. labradorite. Some andesine is also present, and small inclusions of a more basic plagioclase are common in the labrodorite. The hypersthene crystals are larger and show definite crystal boundaries, and a strong green to pink pleochroism. Ilmenite and apatite are commonly included, and felspars occasionally. Secondary biotite fringes many of the hypersthenes, and sometimes infills the

cleavages. The biotite occurs in two forms: (1) a light brown, primary biotite, in flakes with well defined cleavage, often showing flexure as from flowage; (2) a darker secondary biotite, in small unorientated flakes, or aggregates of such, fringing hypersthenes and ilmenites, which originates from a reaction of the phenocrysts and the groundmass. Ilmenite is present as small crystals, also.

A specimen from Mt. Vinegar, No. (2375), contains a notable phenocryst of hypersthene in which all the cleavages are filled with biotite. In No. (2374), from Malleson's Lookout, the groundmass is unusually coarse and variable. Slower cooling than usual has permitted the hypersthene crystals to react strongly with the groundmass, and all stages of the reaction can be seen. Ilmenite is commonly included in the peripheral zones of the hypersthene; or occurs as the nucleus of the biotite aggregates, owing to the complete reaction of the including hypersthene; and the hypersthenes show a tendency to clot. One of the felspars in No. (2332) from the Badger Weir has the appearance of anorthoclase. It shows perfect cleavage, but no twinning, and slight zoning at the margin, where it is free from light patches. It is cut parallel to the (010) face. The extinction angle is 27° showing it to be basic labradorite. The light patches, giving the anorthoclase-like appearance, have a lower index of refraction, straight extinction, and show no twinning, so that they appear to be orthoclase. They are not inclusions since the cleavages are continuous through them. Dr. Summers has suggested the following explanation. It is known that plagioclase forms a solid solution with orthoclase, and that the solubility of the orthoclase decreases as the plagioclase becomes more basic. Probably the solid solution can hold less orthoclase when cold than when at a high temperature, so that on cooling the excess orthoclase has been thrown down, and has segregated into microscopic patches. Such "anorthoclases" are common, but sporadic in occurrence.

Section No. (2335) from Sunny Lodge represents a chilled border phase. The hypersthene crystals show narrow reaction zones of minute granules of a green mineral—probably chlorite after biotite. Zircons, with pleochroic haloes, idiomorphic ilmenite, and small felspars are included in the hypersthene. Secondary biotite occurs along the cleavages and cracks. The ilmenite shows a well developed reaction with the groundmass. Where it abuts the hypersthene or felspar, its fresh character is preserved, but where it comes into contact with the groundmass it loses its metallic lustre at that edge, and the immediately adjacent zone is coloured brown, owing to the formation of a narrow biotite corona. This secondary rim may be granular, but it often shows a columnar structure, the crystals of it growing normal to the edge of the ilmenite crystal (Microphotograph No. 5). Stringers or veins of pyrite are prevalent. They are

later than the consolidation of the rock, filling cracks, and sometimes interposing between crystals and their reaction rims. The pyrite borders both felspar and hypersthene. Sometimes the veins follow the crystal boundaries; others continue straight across groundmass or crystal equally, following cleavage planes or cutting across them at will. No. (2373) from Wade's Lookout is a glassy rock, with coarse patches containing clots of tourmaline and secondary biotite. In No. (2334), from S.W. of Mt. Riddell pipe line the groundmass is very glassy. The hypersthenes have very narrow reaction rims, but the earlier formed ilmenites show very distinct coronas.

8. Granodiorite.

The only outcrop of granodiorite observed in the area occurs as a ridge between the Meyer's Creek road and Donnelley's Creek (Junner, p. 226 and map). It has a medium, holocrystalline texture, and consists of colourless quartz, greenish-white felspar, and green (chloritised) and black biotite. It is often much contaminated with clots of ferromagnesians, and with xenoliths. Garnet is commonly associated with these contaminated patches. The rock is very similar to the Macedon granodiorite. Superficially it resembles the No. 1 porphyrite dyke.

Xenoliths in the Granodiorite.

Numerous xenoliths were collected from the granodiorite at the Maroondah Aqueduct Tunnel dump, south of Donnelley's Weir. Many were as big as one foot or more in diameter. Typically they consist of a core of brown porphyritic rock, showing needles of felspar, and noticeably free from biotite, surrounded by an outer zone of fine-grained, dacitic appearance, consisting of quartz, biotite and calcite, and characteristic large green or white felspars.

The core, No. (2367), is a porphyritic rock with phenocrysts of plagioclase and hypersthene set in a coarsely trachytic groundmass made up equally of plagioclase, quartz, and granular pyroxenes, with subordinate orthoclase and secondary biotite flakes. There is no glass. Ilmenite grains are present. The plagioclase is labradorite with some anorthite. It shows the effects of strong corrosion or solution, and includes numerous granules of hypersthene. Some is schillered. Fresh hypersthene is uncommon as large crystals. It is generally corroded, and much altered to biotite. Smaller crystals of pyroxene are plentiful. The pyroxene varies in composition from hypersthene, through intermediate types, to augite. The extinction angle increases from 0° to 45° as the proportion of the lime molecule increases. Biotite is always subordinate and secondary as coronas, or flakes in the groundmass.

Section No. (2368) shows the junction of the core with the outer zone. The junction is irregular, but sharply defined. The

hypersthenes are increasingly altered towards the outer zone, and form the "phenocrysts." The augite-pyroxene is limited to the groundmass. A remarkable "kelyphitic structure" is developed in an original aggregation of plagioclase and hypersthene phenocrysts (Microphotograph No. 6). It consists of a zone of plagioclase intergrown with needle-like crystals of a pale green ferromagnesian. The femic needles develop with their long axes normal to the edge of the hypersthene crystals. They form only where the hypersthene makes contact with the felspar; where it meets quartz or has been altered to biotite, they are absent. They are pleochroic (?) and have extinction angles of about 25°. They are doubly refractive, but the strength and nature of the double refraction are indeterminable. They seem to be similar to the augitic pyroxene of the groundmass. The felspar associated with the needles has a lower refractive index than the felspar a little removed from the intergrowth. It appears that the lime-rich felspar has reacted with the hypersthene to form a lime-magnesia pyroxene and a more sodic felspar. This intergrowth differs from the "symplektites" recorded by Sederholm (13, pp. 41-46) in that there the intergrown felspar is more calcic than the unaffected felspar. The plagioclase is well schillered.

The outer zone is of a distinctly different character. The "groundmass" consists of a very coarse intergrowth of quartz and felspar, together with ilmenite and biotite. The felspar is entirely altered to calcite and sericite. The large felspar phenocrysts still show albite twinning, and zoning, but have been considerably altered. They are labradorites. There is no hypersthene. The biotite shows bleaching and chloritisation, and the numerous inclusions of ilmenite contained by it suggest that it has replaced the hypersthene in situ. Pyrrhotite is present.

No. (2371) shows the junction of the outer zone with the granodiorite. The groundmass is increasingly coarse and intergrown. The junction is fairly definite, but irregular; and patches of the xenolith are seen within the granodiorite, suggesting assimilation by the latter. The felspars are totally decomposed to calcite and sericite.

The original rock has been a plagioclase-hypersthene-porphyrite, and was probably the hypersthene-dacite. Although this latter rock does not outcrop close at hand, a tremendous amount of erosion has taken place at this locality, and it is quite conceivable that the hypersthene-dacite might have formed the cover into which the granodiorite stoped its way, and that all trace of such a cover has now been removed.

Basic Clots in the Granodiorite.

The granodiorite is commonly contaminated with clots of ferromagnesians. These generally consist of aggregates of biotite, probably remnants from the assimilation of larger xenoliths. Garnet is commonly associated with them, a point of comparison with the granodiorite now outcropping in the tennis court at

Clyde (Braemar House), Macedon. One of these clots, No. (2398), was examined. It contains several crystals of hypersthene associated with a large pink garnet. The garnet appears to have developed from the hypersthene. The hypersthenes mark the centre of the clot; away from this nucleus, the section closely resembles the outer zone of the xenolith described above. Nearly all the hypersthenes show partial alteration to biotite; and they are embedded in a "holocrystalline" intergrowth of quartz and sodic plagioclases (albite and andesine). No orthoclase can be discerned; it is probably in solid solution in the sodic plagioclase.

Further reference to these clots and xenoliths will be made when the hypersthene-biotite reaction relation is dealt with (p. 72).

TABLE OF ANALYSES.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
SiO_2	74·39	74·72	67·85	68·73	65·80	65·83	66·17	61·43	63·27	62·54	64·04
Al_2O_3	14·28	13·05	14·65	13·16	16·87	14·89	14·75	15·95	16·50	16·66	13·58
Fe_2O_3	0·52	0·52	0·64	1·17	3·97	0·73	0·30	1·21	0·68	1·04	0·80
FeO	1·09	1·42	3·40	2·74	1·08	4·63	4·73	5·64	5·10	5·54	4·47
MgO	0·27	0·41	1·39	1·22	1·76	1·88	1·71	2·83	2·48	2·68	2·64
CaO	0·24	0·66	3·05	3·03	3·16	3·13	3·31	4·98	4·18	3·92	3·52
Na_2O	2·78	3·62	2·12	2·30	3·45	2·12	2·45	2·96	2·36	2·66	2·42
K_2O	5·33	4·31	3·19	2·59	2·54	2·32	3·53	2·26	2·68	2·47	2·80
H_2O+	0·22	0·61	2·25	1·86	1·05	2·41	0·66	0·81	0·52	0·46	2·25
H_2O-	0·56	0·13	0·15	0·09	—	0·17	0·01	0·12	0·09	0·17	0·38
CO_2	—	0·08	—	1·50	—	0·47	n.d.	—	—	—	—
TiO_2	0·29	0·16	0·63	0·50	—	0·89	0·97	1·13	1·30	1·20	0·80
P_2O_5	Tr.	0·38	0·32	0·17	—	0·16	1·15	0·53	0·15	0·20	0·18
MnO_2	n.d.	—	—	0·09	Tr.	0·10	0·20	—	0·03	Tr.	Tr.
Li_2O	n.d.	n.d.	n.d.	Tr.	—	—	—	n.d.	Tr.	Tr.	Tr.
S	—	—	—	0·18	—	0·10	0·13	—	0·16	—	—
Cl	n.d.	Tr.	—	Tr.	—	Tr.	0·04	Tr.	—	Tr.	Tr.
Less O_2	—	—	—	0·07	—	0·04	0·06	—	0·08	—	—
Total	99·97	100·07	99·64	99·47*	99·68	99·93*	100·05	99·85	99·50	99·54	99·88
SP. GR.	2·49	—	—	2·69	2·71	2·70	2·71	—	2·76	2·78	2·72

* Not complete.

TABLE OF NORMS.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
Quartz	36·20	35·58	33·36	35·52	26·72	32·10	28·14	18·66	23·91	22·08	25·20
Orthoclase	31·69	25·58	18·90	15·57	15·01	13·90	21·13	13·34	16·12	12·79	16·68
Albite	23·63	30·39	18·82	19·39	29·34	18·82	20·96	25·15	19·91	19·39	20·44
Anorthite	1·11	0·56	13·62	14·18	15·67	14·73	9·73	21·41	20·02	21·68	16·68
Corundum	3·47	2·24	2·75	1·33	2·75	5·50	3·16	0·80	2·35	2·45	2·14
Hypersthene	1·76	2·85	8·00	6·30	5·00	11·07	9·60	14·25	12·47	17·37	12·80
Magnetite	0·70	0·70	0·93	1·62	3·48	1·16	0·42	1·86	1·16	0·93	1·16
Ilmenite	0·61	0·30	1·21	0·91	—	1·52	1·82	2·83	2·43	2·28	1·52
Apatite	—	0·93	0·62	0·31	—	0·36	2·50	1·24	0·31	0·31	0·34
Pyrite	—	—	—	—	—	0·31	0·48	—	0·30	—	—

NORMATIVE CLASSIFICATION.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
Class	1 -	1 -	1 -	1 -	1 -	2 -	2 -	2 -	2 -	2 -	2
Order	3 -	3 -	3 -	3 -	4 -	3 -	4/3 -	4 -	4 -	4 -	4
Rang.	1 -	1 -	3 -	3 -	3 -	2 -	2 -	3 -	3 -	3 -	3
Sub-rang.	3 -	3 -	3 -	3 -	4 -	3 -	3 -	4/3 -	3 -	3 -	3

I. Rhyolite; Archer's Lookout, Narbethong. (N. R. Junner) (6).
II. Rhyolite; Blue Hills, Taggerty (E. S. Hills) (4).
III. Quartz Dacite; Maroondah Dam Quarry (Evans—Mines Department).
IV. Lower Dacite (Morris), Allot. 30C. Railway Cutting, Lilydale-Evelyn (Mines Department) (7).
V. Quartz-biotite-dacite; Black Spur, Narbethong (Stone) (6).
VI. Middle Dacite (Morris); Dandenong Ra., N.E. flank (Mines Department) (7).
VII. Quartz-hypersthene-biotite Dacite; Bladins Quarry, Black Spur, Narbethong (A. B. Edwards).
VIII. Hypersthene Dacite; Mt. Juliet, near Black Spur (Evans—Mines Department).
IX. Upper Dacite (Hypersthene); Upwey (Richards) (8).
X. Dacite (Hypersthene); Braemar House, Macedon.
XI. Granodiorite; Braemar House, Macedon (11).

Evidence of Consanguinity.

There can be but little doubt that the rocks of the area constitute a petrographic province, and are consanguineous. All the extrusive types are porphyritic, and in every case the phenocrysts show marked corrosion, probably resulting from resolution on release of pressure. All possess acid characteristics. Apatite is relatively abundant, and zircons characterise the biotite. Cordierites have been discovered in all the extrusives; and pink garnets typify the series. The felspars show a gradational relation:—

1. Rhyolite—orthoclase (max.); microperthite; albite.
2. Quartz-dacite—orthoclase; andesine (max.); labradorite.
3. Quartz-biotite-dacite—orthoclase (rare); andesine; labradorite (max.); anorthite.
4. Hypersthene-dacite—andesine; labradorite (max.); anorthite.

The rhombic pyroxene, hypersthene, is characteristic of the series, being replaceable by biotite. The quartz phenocrysts decrease in quantity from the rhyolite, through the quartz-dacite, and the quartz-biotite-dacite types, and disappear before reaching the hypersthene-dacite.

The variation diagram (fig. 3) plotted from analyses (calculated to 100% without water) gives a fair curve, approaching that derived from similar rocks in other localities.

Comparison of the ideal, or average variation curves (drawn as close to all the fixed points as possible, and hence representing variation or differentiation under ideal conditions), with that

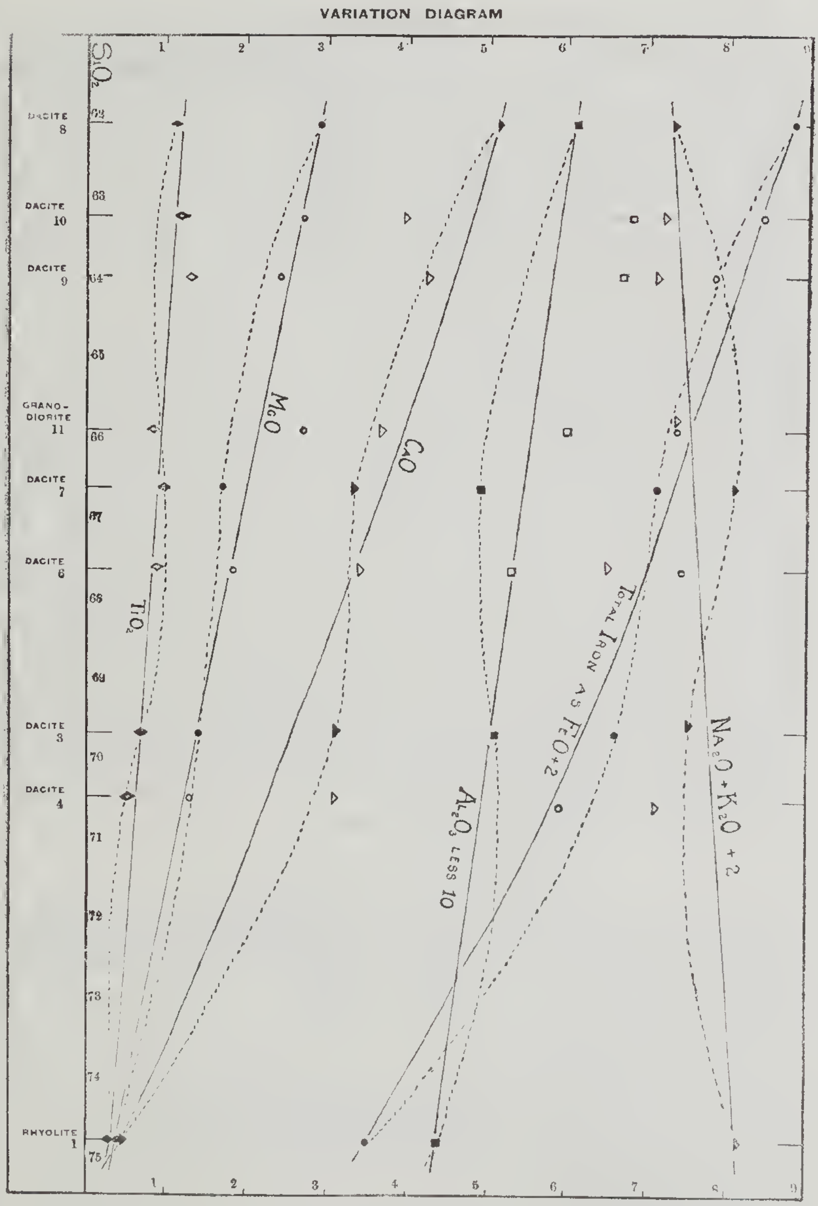

Fig. 3

drawn through the fixed points, and hence representing approximately the actual variation in composition, demonstrates a curious difference between the two curves for any given constituent. In all cases this variation is marked by a compound flexure of the "actual" variation curve, representing an excess or deficit of

the constituent considered in the quartz-biotite-dacite series, with a corresponding deficit or excess of the same constituent in the quartz-dacite. Moreover, related constituents—i.e., those occurring together in the molecular groupings, exhibit similar relations —if one member of the group is in excess, so are all the others. Thus the quartz-hypersthene-biotite-dacite, with regard to its ideal composition, is (1) poorer in: Al_2O_3; Iron as FeO; MgO; CaO. (2) richer in: Na_2O; K_2O; TiO_2; P_2O_5. This suggests that minerals containing alumina, iron, magnesia and lime have sunk in greater degree than required for normal differentiation. The crystals most likely to sink would be those formed in the early stages of crystallisation—the basic lime-rich plagioclases, and the magnesia-iron-rich pyroxenes. Inclusions of basic felspars, in less basic felspars, are very common in the "underlying" hypersthene-dacite. They could have originated in the hypersthene-dacite, but this would require a standstill in the crystallisation, which is not probable. Again the quartz-dacite, with regard to its ideal composition, is (1) richer in: Al_2O_3; FeO (total iron); MgO; CaO; (2) poorer in: Na_2O; K_2O; TiO_2; and P_2O_5. If this rock were of less acid character all these constituents would approach the ideal curve. Taken in conjunction with the very numerous, large quartz crystals in the rock, this suggests an enrichment from the rhyolite in silica-rich crystals,—quartz, and possibly orthoclase. The excess of alumina, iron, lime and magnesia could be accounted for by a sinking of femic crystals from the rhyolite (as evidenced by their almost complete absence in this latter). Cordierite, which is so prevalent in the rhyolite as to suggest a magmatic origin, is also common in this dacite. It might have entered with the quartz.

Sequence of Extrusion.

Insufficient evidence is available to enable a complete sequence of extrusion to be constructed. Indirect evidence strongly supports the order which is suggested below.

6. Granodiorite.
5. Hypersthene-dacite.
4. Quartz-biotite-dacite series $\begin{cases}\text{Q.B. Dacite.}\\ \text{Q.H.B. Dacite.}\\ \text{Porphyrite dyke.}\end{cases}$
3. Quartz-dacite.
2. Rhyolite.
1. Andesite.

The andesite is pre-quartz-biotite-dacite series, since fragments of it are included in the latter. Along the Mt. Monda track it is apparent that the quartz-hypersthene-biotite-dacite in breaking through the rhyolite has brought the andesite fragments with it from below. They must therefore be regarded as pre-rhyolite.

In the Marysville-Taggerty district, Hills (5) has placed the andesite as earlier (?) than the rhyolite; while Junner (6) has made them post-rhyolite (?).

The rhyolite precedes the quartz-biotite-dacite series, since both the porphyrite dyke (No. 1) and the quartz-hypersthene-biotite-dacite are intrusive into it, and the quartz-biotite-dacite contains xenoliths of rhyolite. It is also older than the quartz-dacite since pebbles of rhyolite are found in a volcanic agglomerate formed by the quartz-dacite; and since this dacite is overlain by the hypersthene-dacite, the relative age of the rhyolite is fixed.

Direct evidence of the relative superposition of the quartz-dacite and the quartz-biotite-dacite series is lacking, but field relations and indirect evidence point to the quartz-dacite as the earlier. At the volcanic centre in the quartz-dacite on the western side of the Maroondah Dam no quartz-biotite-dacite fragments have been found in the pyroclastics, although sedimentary breccia and lapilli abound. This negative evidence, together with the fact that at the foot of this steep volcanic hill the two dacites are in close proximity, suggests that the quartz-biotite-dacite abuts against the quartz-dacite, or rests upon it. This view is supported by the fact that bores about the dam site show a thickness of over 100 ft. of quartz-dacite below the present water level, without passing into any other type of rock, whereas the junction of the two dacites is above the water level.

At Carter's Gap and below Mt. Juliet, two interpretations of the sequence are possible; the more probable of the two places the quartz-biotite-dacite on top of the quartz-dacite; and this view is supported by the variation diagram.

The quartz-dacite closely resembles the Lower Dacite of the Dandenong series, while the quartz-biotite-dacite compares equally well with the Middle Dacite of that series.

The hypersthene-dacite overlies the quartz-dacite at Carter's Gap, near the 1000 ft. contour on the Mt. Juliet track, and again on slopes below Mt. Riddell. Its relation to the quartz-biotite-dacite is indefinite, since the two types are not in contact. It outcrops over the higher parts of the ranges, and its more basic character suggests that it is the latest member of the extrusives. It closely resembles the Upper Dacite of the Dandenong Range series, which is the uppermost member of three types, the lower two of which agree closely with the quartz-dacite and the quartz-biotite-dacite.

Finally, the granodiorite intrudes into the Silurian sediments, converting them locally into hornfels, and probably causing the pyritisation and carbonisation of the rhyolite blocks found in the dump material at the Echo Tunnel. Large xenoliths of, apparently, recrystallised hypersthene-dacite are very commonly included in the granodiorite at the tunnel south of Donnelley's

Weir. Small quartz veins are found penetrating the hypersthene-dacite at Mt. Juliet; and the dacites in contact with the granodiorite in the neighbouring areas of Nyora and Warburton have been rendered schistose. Elsewhere, at Selby (9, 10), and Macedon (11), the granodiorite is post-hypersthene-dacite.

Correlation with Related Areas.

The following table of rocks in related areas shows that the rocks of the Black Spur Area disclose an important link between the definitely Upper Devonian igneous rocks of Blue Hills (Taggerty) (4, 5) and the Devonian igneous rocks of other areas.

BLUE HILLS (Taggerty) (4, 5)	MARYSVILLE (5)	BLACK SPUR (Healesville)	LILYDALE (Mt. Dandenong) (7)	MACEDON (11)
	8. Granodiorite	6. Granodiorite	6. Granodiorite	2. Granodiorite
		5. Hypersthene-Dacite	5. Hypersthene-Dacite	1. Hypersthene-Dacite
	7. Dacite			
		4. Quartz-Biotite-Dacite series	4. Middle-Dacite	
		3. Quartz-Dacite	3. Lower Dacite	
			2. Upper Toscanite	
			1. Lower Toscanite	
5. Rhyolite (a)	6. Rhyolite (a)	2. Rhyolite		
4. Rhyolite (b)	5. Rhyolite (b)			
	4. Andesite (?)	1. Andesite (?)		
3. Melaphyre (Basalt)	3. Melaphyre (Basalt)			
2. Tuffs (and foss. seds.)	2. Tuffs			
1. Basal-Congl.	1. Basal-Congl.			
		UNCONFORMITY		
SILURIAN	SILURIAN	SILURIAN	SILURIAN	ORDIVICIAN

Magmatic Differentiation.

Following Bowen (1) we may postulate a parental magma of basaltic character. This is in agreement with the occurrence of basalts and melaphyres described by Hills at Taggerty (4) and at Marysville (5) as the basal members of this igneous series.

Differentiation of this magma by sinking and zoning of crystals gave rise to an upper layer of andesitic composition. When this had partially crystallised, extrusion occurred, probably at numerous points but without producing any widespread flow.

The magma body, continuing its course of differentiation, ultimately reached a state of more or less stratification in its upper layers corresponding to:—

Rhyolite
Quartz-dacite
Quartz-biotite-dacite
Hypersthene-dacite

representing the increasingly basic nature of the rocks grading downwards. This stratification is suggested by the gradational relation between the extrusive types, and their acid to basic order of extrusion. Crystallisation was well advanced by this stage.

An explosive extrusion of the upper layer of rhyolite occurred, giving rise to tuffs and breccias. The violence died down, and viscosity increased with loss of mineralisers, so that the later rhyolite welled up into a massive ridge. There were probably several centres of extrusion.

With the consolidation of the rhyolite, the rents in the magma chamber closed, and the gases again accumulated, to lesser extent than previously, in the upper layers. A second explosive extrusion, of quartz-dacite, followed, with less violence. It was accompanied by an outpouring of lava, fluid despite its partially crystalline state, as shown by its wide outcrop and glassy groundmass.

The magma chamber resealed, and stoping up, the magma repeated its attempt to break the cover. Differential flotation of the rhyolite gave rise to weakness or fissures, which was followed by intrusion of dykes and sills of quartz-hypersthene-biotite-dacite into these weakened areas and along junctions of rhyolite and Silurian sediments. Simultaneously a breaking of the cover allowed the main part of the magma to overflow as quartz-biotite-dacite.

Consolidation blocked the channels of extrusion, and when the rising magma burst through again, it took a fresh course through the Silurian, as evidenced by the hornfels in the hypersthene-dacite, rather than through the now thickened igneous cover. The lava poured out was more viscous than the earlier lavas, as evidenced by its crystalline groundmass; or it cooled more slowly. It was a much larger flow than those preceding it, being extruded, probably, through fissures produced by a partial collapse of the roof of the magma chamber.

When this extrusion ceased the remaining magma may have been relatively more basic, or it may have been of much the same composition, only part of the "layer" having been extruded. A second period of differentiation and stoping set in, and the magma commenced to stope up through the thick igneous cover that sealed it. Its energy failed before it could complete its task, but it came close to the surface. Erosion has uncovered patches of the granodiorite, as which it consolidated, about the margins of the igneous rocks.

The Reaction Relation—Hypersthene to Biotite.

Examination of the hypersthene-dacites of Victoria has demonstrated the existence of a relation between hypersthene and biotite. It was first observed by Skeats (9) and Richards (8) at Selby, in the metamorphosed zone of the dacite, and later by Skeats and Summers (11) at Macedon, under similar conditions. In both areas a hypersthene-dacite is intruded by granodiorite. In the metamorphic aureole, as the granitic contact is approached, the hypersthene is increasingly replaced by biotite, until at the contact, biotite only is found. The production of biotite was accompanied in both cases by the deposition of quartz.

Richards (8) separated and analysed the hypersthene and biotite from Selby. He found that an addition of an orthoclase molecule to the analysed hypersthene molecule would give the biotite molecule, as determined chemically, and excess quartz. This agreed with the petrological facts. He suggested the following equation:—

Hypersthene + Orthoclase + Water = Biotite + Quartz.

Summers (12) and Hatch (3, p. 190) view this reaction as of more than metamorphic significance, and consider that it is related to the ferromagnesian discontinuous reaction series of Bowen (1). The hypersthene is thought to crystallise out at a high temperature, become unstable with cooling, and to react with the orthoclase and water molecules of the fluid magma to form biotite and quartz.

Summers (12) found the body of the Macedon dacite to be practically free from biotite. He inferred "that the temperature of the magma at the time of extrusion was rather higher than the reaction temperature between hypersthene and alkali felspar, but that in parts the cooling after the extrusion was sufficiently slow for some reaction to take place." He described quartz-porphyrites from the Strathbogie Ranges and the Tolmie Highlands as containing biotite and rare examples of corroded hypersthenes, and considered that these rocks were examples in which the temperature at which crystallisation had ceased had been sufficiently low for the reaction between hypersthene and felspar to go almost to completion.

The dacites of the present area contribute a considerable amount of evidence in support of a reaction of this character. They reveal: (1) the incipient stages of the reaction, in the hypersthene-dacite; (2) the reaction well under way, in the quartz-hypersthene-biotite-dacite; (3) the final stages of the reaction, in the quartz-biotite-dacite; (4) an abnormal retention of hypersthene in xenoliths in the granodiorite; (5) an association throughout the series of hypersthene and biotite, without any trace of an intermediary amphibole. It is necessary then, to show why the hypersthene should form biotite directly, instead of following the reaction series of Bowen (1, p. 60); and to investigate the conditions controlling the reaction.

If the cooling were intratelluric throughout, as in the granodiorite, a rock should result, containing not hypersthene, but hornblende and biotite. This is illustrated by the hornblende-granodiorite at Selby. Temperature, however, while an essential factor in the controlling of the action, is not of itself sufficient. This reaction is not the spontaneous breaking down of a complex form to simpler forms, resulting from a sudden instability, but a chemical double decomposition between hypersthene and orthoclase, so that an "environment" factor must be considered. The effect of cooling is to render the hypersthene "potentially reactive"; but if it is shielded in some way from the other reactants no biotite will form. This is clearly demonstrated by the presence of fresh, primary hypersthene in the xenoliths and clots in the granodiorite (p. 64). The original rocks, of which these are the remnants, must have been raised to the temperature of the granodiorite and then have cooled with it intratellurically, so that the hypersthene would have been rendered "potentially reactive"; and if, as supposed, the original rock was the hypersthene-dacite, the conditions would appear ideal for the transformation of the hypersthene into biotite. It has been shown however, that the inclusions were completely recrystallised, except for the more basic phenocrysts, and that in the recrystallisation, lime from the felspars entered the ferromagnesians, and left the plagioclase soda-rich (Nos. 2368; 2398). Orthoclase seems to have disappeared from the recrystallised rock. Knowing that the albite-plagioclases can hold a greater amount of orthoclase in solid solution than the original basic plagioclases could, it seems probable that the orthoclase has formed such a solid solution; and that the hypersthene has thus been protected.

In the normal hypersthene-dacite such shielding factors are absent, and the temperature is the responsible factor. Extrusion of the lava at the hypersthene-labrodorite stage of crystallisation would occasion a sudden and very rapid cooling, which slackened in rate as the lava approached consolidation, after the manner of the cooling curve shown (fig. 4). The cooling in the amphibole range would be too rapid to permit hornblende to develop, and although slowing down in the biotite range, the lava would be too close to consolidation for more than an incipient reaction to take place. Variation in the rate of solidification, as marked by glassy or microcrystalline groundmasses, is accompanied by the development of narrow or deep reaction coronas of biotite, corresponding to the rapid or (relatively) slow solidification.

In the quartz-biotite-dacite and the quartz-hypersthene-biotite-dacite, the composition is about 4.5% richer in SiO_2 and about 5% poorer in ferromagnesians than that of the hypersthene-dacite, i.e., there is a large relative increase in free "quartz." When these magmas reached the temperature at which they were intruded, this extra silica had crystallised as quartz, and since in both these rocks there is still hypersthene, varying

markedly in amount with the manner in which the two varieties cooled, we can safely consider the reaction as commencing at a temperature below the inversion temperature of tridymite-quartz, 870°C. In these more acid rocks the consolidation tem-

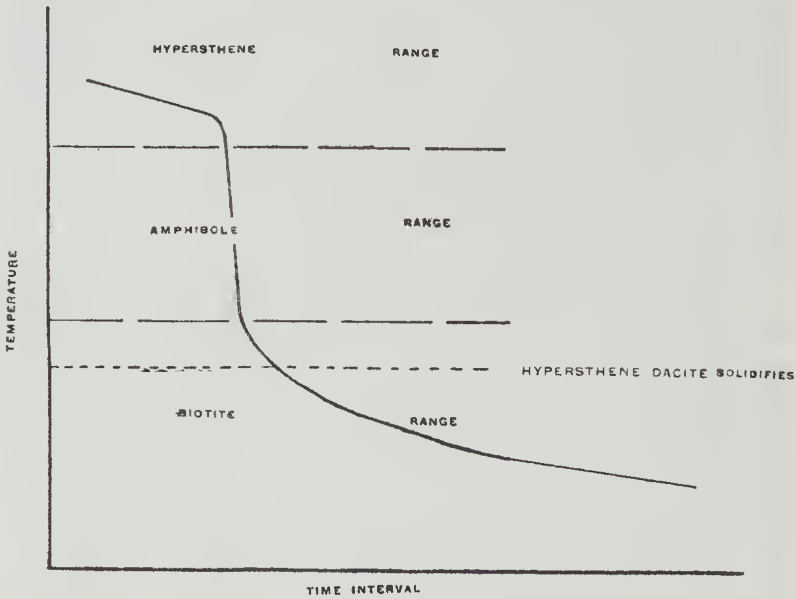

Fig. 4

perature is probably a little lower than for the hypersthene-dacite, and there would be a little less initial hypersthene, both of which factors would contribute to a more complete reaction.

A lower limit to the "stability" of the hypersthene is determined by the temperature of consolidation of normal granitic magmas, viz., 500°C. The temperature at which hypersthene becomes "potentially reactive" is probably in the neighbourhood of 650°C.-700°C. This does not mean that hypersthene cannot continue to be present below this temperature; but only that it will react if allowed to by its environment.

The metamorphic reaction first observed, represents a special case of this reaction. In the metamorphic zones described, the hypersthene-dacite was extruded, and quenched before the hypersthene could react in the normal way, i.e., following the reaction series. An incipient hypersthene to biotite reaction occurred with consolidation. The intrusion of granodiorite reheated the rocks to a temperature below the temperature of "stability" for hypersthene. It also increased the molecular activity of the minerals, giving their molecules opportunity or tendency to stabilise at the new temperature; and accordingly the hypersthene reacted to form biotite in proportion to its infused energy, which increased in the direction of the contact.

It is postulated that this reaction of hypersthene with orthoclase and water to form biotite and quartz is the natural path of the ferromagnesian discontinuous reaction series, when the hypersthene fails to react normally from some external cause, viz., extrusion and the rapid cooling resulting. The reaction is a double decomposition, so that environment is of equal importance with temperature.

The existence of primary charnockites (hypersthene-granites) and biotite-gabbros might be explained by this "environment" factor. Thus it is found very generally that charnockites, particularly the intermediate types, have dominant soda-felspars; and that although they contain abundant potash, it rarely appears as orthoclase, but enters into solid solution with the soda-felspar, and is therefore not available to react with the pyroxene. With gabbros the dominant felspars are anorthitic, so that any potash present is insoluble, and will so be free to attack the pyroxene.

Ilmenite to Biotite Reaction.

It was shown by Skeats (10) and Richards (8) at Selby that as the result of metamorphism, ilmenite reacted to form biotite. Richards showed from his analyses that the addition of orthoclase to ilmenite will give a biotite very low in magnesia, and very rich in ferrous oxide. Such a biotite would possess optical properties similar to the biotite actually observed replacing the ilmenite.

In the rocks here described, it has been found that this reaction of ilmenite with orthoclase or other molecules, to form a secondary biotite, is a pyrogenetic change rather than specially characteristic of a metamorphic zone. The microscopical evidence of the change has been described (p. 62, No. 2335). The reaction commences earlier than the similar reaction of hypersthene, and seems to have the effect of initiating the hypersthene-biotite reaction, if the ilmenite is included in the hypersthene, and to act as a catalyst once the action is started.

The microphotograph No. 5 shows a typical example of a biotite corona about an ilmenite crystal which has reacted with the groundmass.

Sederholm (13) describes a reaction between ilmenite and plagioclase to give biotite in similar growths. He summarises the work of several previous authors on the subject. This ilmenite-plagioclase reaction is described as general in gabbros and dolerites. Richards has shown that there is about 14.5% plagioclase in the groundmass of the hypersthene-dacite, so that the ilmenite could as easily react with this as with the orthoclase.

Bibliography.

1. Bowen, N. L.—The Evolution of Igneous Rocks.
2. Dunn, E. J.—Gold and Tin Workings at Tin Creek, near Buxton. *Rec. Geol. Surv. Vic.*, ii., (2), pp. 105-108, 1907.

3. Hatch, F. H., and Wells, A. K.—The Petrology of Igneous Rocks.
4. Hills, E. S.—The Geology and Palaeontography of the Cathedral Range and the Blue Hills, in North-Western Gippsland. *Proc. Roy. Soc. Vic.*, (n.s.), xli., (2), pp. 176-201, 1929.
5. Hills, E. S.—Note on the evidence of age of the Dacites and Associated Igneous Rocks in the Marysville-Taggerty District, Victoria. *Ibid.*, (n.s.), xlii., (1), 1929.
6. Junner, N. R.—Petrology of the Igneous Rocks near Healesville and Narbethong. *Ibid.*, (n.s.), xxvii., (2), pp. 261-285, 1914.
7. Morris, M.—Geology and Petrology of the District between Lilydale and Mt. Dandenong. *Ibid.*, (n.s.), xxvi., (2), 1913.
8. Richards, H. C.—On the Separation and Analysis of Minerals in the Dacite of Mt. Dandenong, Victoria. *Ibid.*, (n.s.), xxi., (2), p. 528, 1909.
9. Skeats, E. W.—Gneisses and Dacites of the Dandenong District. *Quart. Jour. Geol. Soc.*, lxvi., pp. 430-469, 1910.
10. Skeats, E. W.—On the Gneisses and Altered Dacites of the Dandenong District (Victoria), and their relations to the Dacites and Granodiorites. *Geol. Mag.*, Dec. V., vii., p. 134, 1910.
11. Skeats, E. W., and Summers, H. S.—The Geology and Petrology of the Macedon District. *Bull. Geol. Surv. Vic.*, 24, 1912.
12. Summers, H. S.—The Relationship between the Dacite and Granodiorite in Victoria. *Proc. Roy. Soc. Vic.*, (n.s.), xxxv., 1923.
13. Sederholm, J. J.—On Synantectic Minerals and Related Phenomena. *Bull. Comm. Géol. Finlande*, 48, 1916.

Explanation of Plate VIII.

1. Quartz-dacite. Showing typical corroded quartz and sericitised felspar.
2. Quartz-biotite-dacite.
3. Quartz-hypersthene-biotite-dacite. Shows quartz (right-top), hypersthene (central) reacting with orthoclase (lower left), the junction being marked by secondary biotite.
4. Intergrowth of hypersthene (light) and biotite (black) in the hypersthene-dacite.
5. Corona of secondary biotite surrounding ilmenite.
6. Kelyphitic intergrowth round hypersthene in xenolith in the granodiorite. The hypersthene is dark with light patches of secondary biotite along the edge.